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Production of 6.5 km GdBCO conductors for 66 kv-5 kA class HTS model cable

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Abstract

We have fabricated coated conductors for 66 kv-5 kA class 3-in-One 15 m HTS model cable. One of the targets of the cable is low AC loss of 2W/m/phase at 5kA. For this purpose, the coated conductors that are 2 mm wide and 4 mm wide were used for the cable. For the production, we have been developing the stable production technique of high I_c coated conductors. Recently the coated conductors for the cable were provided for the cable manufacturing.

Keywords: Coated conductors; Power transmission cables; PLD

1. Introduction

Recently, coated conductors (CCs) are expected to be used for superconductor power equipment. Sumitomo Electric has been developing the production of CCs and large current cable under a Japanese national project for development of materials & power application of CCs since 2008. In FY2012, a 15 m long cable system (66kV, 5kA, 3-in-One) will be tested. Low AC loss at less than 2W/m/phase at 5kA is one of the targets for the cable. To fabricate CCs for the cable system, we have been developing stable production technology. In July 2012, we completed the production of the CCs and have provided a manufacturing process for the cable. The typical I_c value of the CCs is over 300 A/cm-width. For reduction of the AC loss of the cable, 2 mm wide and 4 mm wide CCs were fabricated.

2. Fabrication process of the CCs and development

2.1. Substrates

We used 30 mm wide clad type textured metal tapes as the substrates. The substrates are based on 0.1 mm thick stainless steel. A textured Cu layer is located on the stainless steel base, and the Ni plating layer is formed on the Cu layer epitaxially. The hysteresis loss of the substrate is smaller than that of Ni-W5% substrate [1]. The substrates also have high strength and wide tapes are available. The FWHM of ϕ-scan is around 5 degrees and surface roughness Ra is less than 10 nm.

2.2. Buffer layers

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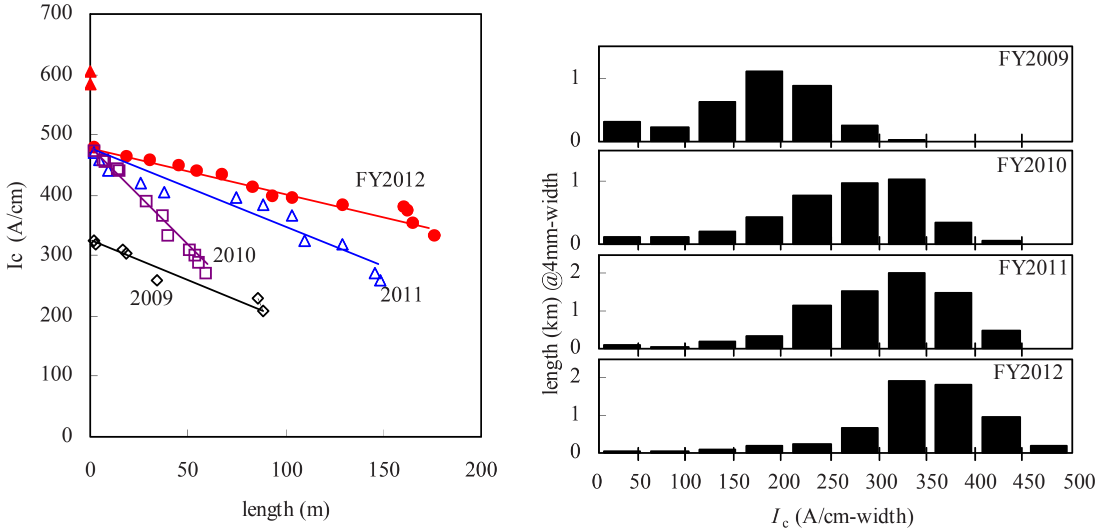

(a) (b)

Fig. 1. Recent progress of (a) I_c vs. length; (b) I_c distribution

Three layers of buffer layers are deposited by RF sputtering on the substrate. First a CeO_2 layer is deposited as a seed layer. A YSZ layer, which prevents Ni diffusion, is formed on the seed layer, followed by the CeO_2 lattice matching layer deposition. A good (100) cube textured ratio was confirmed by XRD along the whole length of the tape, at 1 m each.

2.3. Superconductor layer and Ag protecting layer

The pulsed laser deposition (PLD) method is applied to the deposition of a $GdBa_2Cu_3O_x$ (GdBCO) superconductor layer on the buffer layers. We have been developing the stable deposition technique as well as a high I_c of the superconductor layer. As to the high I_c development, we installed a high power laser to the PLD equipment in 2010, and it was effective in improving I_c [2]. Then we optimized the PLD conditions like tape speed and laser power, to stabilize the PLD process. High I_c distribution and long length CCs were acheived. Fig. 1 shows progress in I_c vs. length and I_c distribution. Recently a high I_c of over 600 A/cm-width was obtained in short samples.

After the superconductor layer deposition, the Ag protecting layer is formed through DC sputtering, followed by oxygen annealing.

2.4. Slitting

The 30mm wide HTS tapes are slit to 4mm or 2mm width after annealing. First, to check the I_c of the HTS tapes, the tapes are slit to three 10 mm width temporarily, and I_c was measured by using the Hall prove method. Good I_c tapes are then slit to 4mm or 2mm width. Then six pieces of 4 mm wide tapes are cut from a 30 mm wide tape.

Because the AC loss of the cable is affected by J_c degradation width at tape edge caused by slitting [3], two slitting methods, mechanical slitting, and laser slitting, were tested to reduce edge degradation width. For the mechanical slitting, optimizing slitting condition allowed about 0.2 mm of degradation width. However the CCs which were laser slit in ISTEC-SRL showed smaller degradation width [3].

From that, the laser slit was used for the 2 mm wide CCs. The 4 mm wide CCs were slit by laser slitting and mechanical slitting because of slitting capacity.

2.5. Cu stabilizing layer plating and I_c measurement

The 4 mm and 2 mm wide CCs are electroplated with 20 μm of Cu as stabilizing layer through the reel-to-reel process. Finally transport I_c of the tapes is checked by each 1.5 m for the whole length. The I_c is also checked using the Hall prove method to remove short defect region.

Table 1. Required specifications for CCs

Layer		Width of CCs	Piece length	Number of CCs (1 core)	I_c (A/cm-width)
Conductor (4 layers)	1st	4 mm	18 m	15	330
	2nd		18 m	15	345
	3rd		19 m	15	365
	4th	2 mm	21 m	27	370
Shield (2 layers)	1st	4 mm	19 m	24	330
	2nd		18 m	26	285

3. Production of the CCs for 15 m cable

The required specifications for CCs were clarified through the development of elemental technologies of the cable. The cable core includes 4-layers of conductor layers and 2-layers of HTS shield [4]. 2 mm wide CCs are used for outer layer (4th layer) of the conductor layers to reduce AC loss [5]. For the other layers, 4 mm wide CCs are used. Required I_c and piece length for each layer is shown in table 1.

Production of CCs for 15 m cable was conducted from June 2011 to July 2012. Fig. 2 shows the processed length of each month. From June 2011 to May 2012, 24.5 km (@ 4mm width) substrates were submitted to buffer layer deposition. All tapes deposited buffer layers were checked by X-ray diffraction measurement for the whole length to confirm the cube-textured ratio. Good cube textured tapes of 22.8 km (@4 mm width) were provided for the PLD process, and superconductor layer deposition was performed from September 2011 to July 2012. After Ag protecting layer deposition and oxygen annealing, 30 mm wide tapes were slit to 10 mm width and the I_c was checked using the Hall prove method. Tapes expected high I_c were selected to slit to 2 mm or 4mm width. After the electroplating of copper stabilizer, I_c of the CCs was measured with the transport method. The I_c measurement was performed for 12.3 km CCs. As a result, 8.1 km of CCs having an I_c of over 300 A/cm-width were produced. In FY2012, 10.6 km (@ 4mm width) of substrates were submitted and 4.9 km of CCs having I_c over 300 A/cm-width were produced. So the yield of CCs having I_c over 300 A/cm-width was 45 %.

Finally, the surface defects region was omitted and CCs which satisfied piece length were provided to the cable manufacturing process. I_c distribution of the CCs supplied to 15m cable process is shown in Fig. 3 for 4 mm wide and

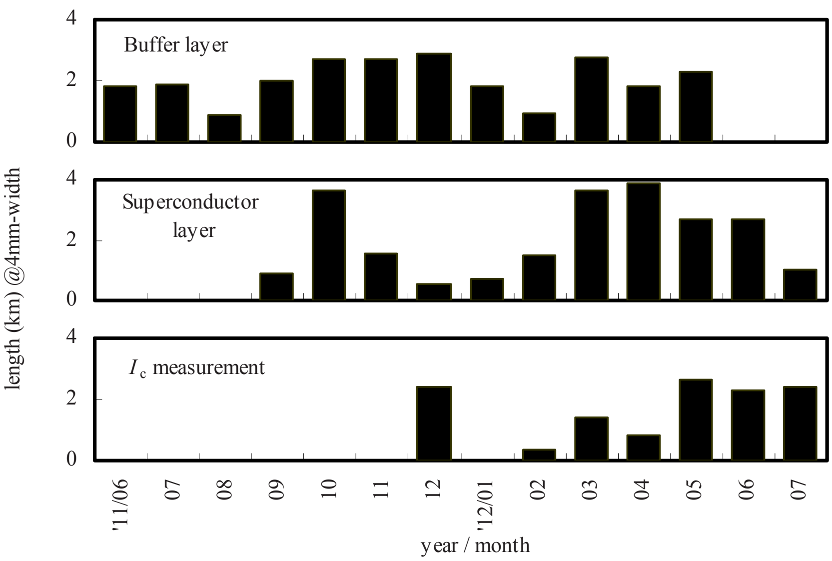

Fig. 2. Recent progress of (a) I_c vs. length; (b) I_c distribution

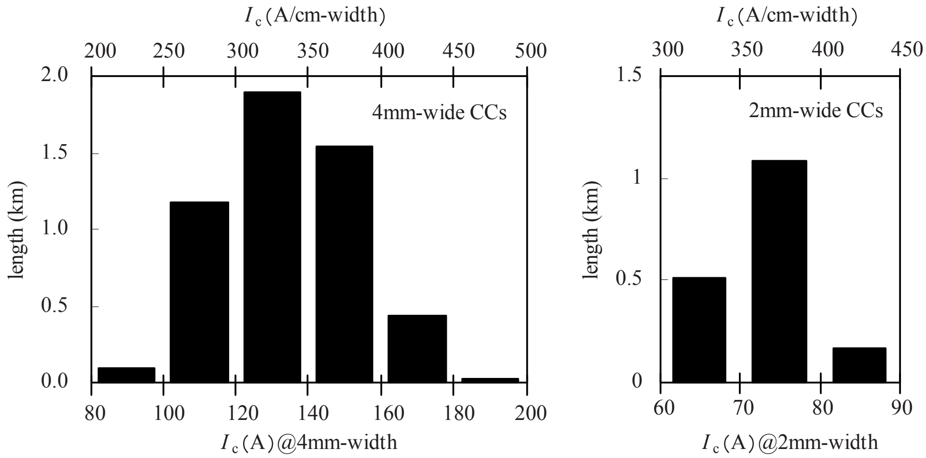

Fig. 3. I_c distribution of the CCs supplied to 15m cable process

2mm wide CCs. The 5.2 km of 4 mm wide CCs and the 1.7 km of 2 mm wide wires were supplied for the cable manufacturing process.

4. Conclusions

We have fabricated CCs for 66 kv-5 kA class 3-in-One 15 m HTS model cable. From June 2011 to July 2012, 24.5 km (@4mm width) of the substrates were submitted to the buffer layer deposition and 8.1 km of the CCs having an I_c of over 300 A/cm-width were produced. 1.7 km of 2 mm wide CCs and 5.2 km of 4 mm wide CCs are used for the cable system. The cable system will be tested by Feb. 2013.

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References

[1] T. Nagaishi, Y. Shingai, M. Konishi, T. Taneda, H. Ota, G. Honda, *et al*, Physica C 469 (2009) 1311–1315.
[2] K. Abiru, Y. Shingai, M. Konishi, K. Ohmatsu, IEEE Trans. Appl. Supercond. 21 (2011) 2941-2944.
[3] N. Amemiya, Q.Li, R. Nishino, K. Takeuchi, T. Nakamura, K. Ohmatsu, *et al* Physica C 471 (2011) 990–994.
[4] M. Ohya , T. Masuda , N. Amemiya , A Ishiyama , T. Ohkuma, Physics Procedia 27 (2012) 364 – 367.
[5] N. Amemiya, Q. Li, K. Ito, K. Takeuchi, T. Nakamura, T. Okuma, Supercond. Sci. Technol. 24 (2011) 65013.